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Cognitive processes and math performance: a study with children at third grade of basic education

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Abstract The present study aims to examine the relationship between cognitive factors and mathematical achievement in primary education. Participants were 103 Portuguese third grade students, aged 8 and 9. All participants completed a battery for working memory (WMTB-C), a test of general intelligence (Raven's Progressive Color Matrices), a selective attention test (*d2*), and mathematical exercises (arithmetic story problems and measurement skills). Data suggested significant correlations between math performance, executive, visuo-spatial sketchpad and *g* factor. Our findings suggest the importance of the cognitive factors in two mathematical domains considered. In consonance with the research in this area, we conclude that working memory (WM) assumes an important role in different math curricular achievements.

Keywords Mathematics performance · Working memory · Selective attention · *g* factor · Basic education

Introduction

Mathematical performance is made up of a number of components such as basic knowledge of numbers, memory for arithmetical facts, understanding of mathematical concepts, and ability to follow problem-solving procedures (Dowker 1998). These elementary arithmetic skills increase over time (Siegler 1988; Siegler and Shrager 1984). In the beginning, at a basic level, children start by using fingers or other concrete references to help them with the counting process. From these simple strategies, children move on to auditory counting,

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starting with the addition process and continuing up to the subtraction process. Through experience and improvements in working memory (WM), children are better able to mentally keep track of the counting process, and thus gradually abandon the use of manipulative and fingers for verbal counting (Geary 2006).

Although research has increased the understanding of relations between cognitive processes and mental arithmetic, less is known about how other math domains (e.g., arithmetic story problems and measurement skills) are related to cognitive capacities in the first school years. The cognitive process associated to the measurement process implies the subdivision of continuous quantities (such as length) in order to make them countable and comparable. Hence, measurement skills are complex cognitive processes associated with both number and arithmetic operations (Sarama and Clements 2009). Moreover, there has been some discussion in the literature about the role of memory, attention, and intelligence in mathematical performance and in the identification and treatment of mathematics difficulties (Fuchs et al. 2006; Raghubar et al. 2010). In order to clarify these questions, we aim to study the association between academic performance in mathematics and some cognitive functions related with general intelligence (*g*), selective attention, and WM (CE central executive, phonological loop, and visuospatial sketchpad).

Math performance and working memory (WM)

Some findings suggest that WM is related to a variety of mathematical outcomes when other cognitive and academic factors are taken into account, suggesting a particular role for WM in mathematical performance (Alloway 2009; Fuchs et al. 2005; Geary et al. 1991; Hitch and McAuley 1991; Lee et al. 2004; Lee et al. 2009a; Passolunghi and Siegel 2004; Swanson and Sachse-Lee 2001; Swanson and Beebe-Frankenberger 2004; Wilson and Swanson 2001).

Many studies have used the WM model of Baddeley and Hitch (1974, see also Alloway 2009; Hitch and McAuley 1991) to understand the mathematics performance of school age children. Baddeley (1986) defined WM as a system responsible for temporarily storing and manipulating information needed in the execution of complex cognitive tasks (e.g., learning, reasoning, and comprehension). Recently, this model has been empirically tested (Ferreira et al. 2011). WM consists of four components: the central executive, the phonological loop, the visuospatial sketchpad, and the episodic buffer (Baddeley 2000). The CE is responsible for the high-level control and coordination of information flow through WM, including temporary activation of long-term memory. It has also been linked with control processes such as switching, updating, and inhibition (Baddeley 1996). The CE is supplemented by two slave systems specialized in information storage within specific domains. The phonological loop provides temporary storage for linguistic material, and the visuospatial sketchpad stores information that can be represented in terms of visual or spatial content. The fourth component is the episodic buffer, which is responsible for integrating information from different components of WM and long-term memory into unitary episodic representations (Baddeley 2000).

Recent studies provided insight into the complexity of the relationships between WM components and math (Bull and Scerif 2001; Lee et al. 2004; Lee et al. 2009a). For example, the CE is assumed to be responsible for adding numbers (Logie et al. 1994), to play a crucial role in the speed of solving mental arithmetic problems and in decision making (Baddeley 1986; Logie 1993), basic calculation proficiency (Cowan et al. 2011), and contributes to individual differences in children's mathematics achievement (Bull and Scerif 2001; Gathercole and Pickering 2000b; Holmes and Adams 2006; Swanson and Kim 2007). The phonological loop is implicated in counting (Logie and Baddeley 1987), multiplication (Lee and Kang 2002), and arithmetical reasoning ability (Henry and MacLean 2003). It has been suggested that the role of phonological WM constrains vocabulary growth during the first childhood years (Gathercole and Baddeley 1993) and retains verbally coded information about mathematical problems, and also supports the retrieval of mathematical facts from long-term memory (Holmes and Adams 2006). Hecht et al. (2001) showed that the phonological loop was a unique predictor of mathematics achievement in primary school children. A recent study by Swanson and Kim (2007) demonstrated that phonological storage was uniquely related to mathematics performance in 6- to 10-year-olds. However, not all studies have reported evidence in favor of this relationship. For example, Gathercole and Pickering (2000b) showed that phonological loop ability was correlated with mathematics performance in 7- to 8-year-olds, but this association disappeared when controlling for CE ability (see also Holmes and Adams 2006). Bull and Johnston (1997) demonstrated that 7-year-old low mathematics achievers and high mathematics achievers differed in phonological loop measures, but this difference disappeared when controlling for reading ability.

At the same time, research on the influence of the visuospatial sketchpad in mathematics development emerged from the belief that children with mathematical disabilities showed impairments in visuospatial sketchpad tasks (Bull et al. 1999; Gathercole and Pickering 2000a; McLean and Hitch 1999; Van der Sluis et al. 2005). Also, some authors have reported significant associations between the visuospatial sketchpad and individual differences in mathematics achievement at various ages throughout primary school (Cowan et al. 2011; Holmes and Adams 2006; Holmes et al. 2008; Jarvis and Gathercole 2003). Moreover, it appears that the contribution of the visuospatial sketchpad in mathematics achievement differs as a function of age and that this contribution may be especially important during the initial stages of mathematics learning. For example, Rasmussen and Bisanz (2005) showed that the visuospatial sketchpad was associated with mathematics in preschoolers, but this association disappeared in first graders. Recent reports by Holmes and Adams (2006) and Holmes et al. (2008) indicated that the visuospatial sketchpad has a stronger role in 7- and 8-year-olds' mathematics performance compared with that of 9- and 10-year-olds'. In adolescents, relations between visuospatial WM and math have been found (Kyttälä and Lehto 2008; Reuhkala 2001) with some differences reported for static and dynamic measures of visuospatial WM, depending on the particular math skill being measured (e.g., static related to mental arithmetic and dynamic related to geometry and word problem-solving). In general, the findings from studies of WM components and math performance in samples of elementary school children and adolescents suggest that executive and visuospatial skills may be important in learning and applying new mathematical skills/concepts, whereas the phonological loop may come into play after a skill has been learned. By including separate WM dimensions, we intend to understand which dimension plays a higher contribution with math performance.

Math performance and selective attention

Selective attention—a central concept in human performance and learning—is defined as the ability to activate and inhibit information (Hasher et al. 1999; Posner and Peterson 1990). Several authors describe such ability as quite similar to Spearman's *g* factor of intelligence. For example, on Pascual-Leone cognitive–developmental approach, the mental attention (M) is assumed as the mental effort on problem-solving (Pascual-Leone and Baillargeon 1994). Thus, one of the most consistent findings in math disability research in recent years is the relation between maths and attention (Bull and Johnston 1997; Fuchs et al. 2006;

Raghubar et al. 2009). There is some evidence that children with mathematic difficulties are less skilled in allocating their attention resources and in monitoring the problem-solving process (Geary et al. 1991). Deficits on selective attention affect the quality how children initiate, inhibit, direct, and retrieve relevant information in processing different tasks (Geary et al. 1999; Hasher et al. 1999). An example of this is comprehension of the instructions presented on mathematical problem-solving (Jordan et al. 2003).

Selective attention is quite similar to WM, as its measures are related to those of the CE function in WM (Cantor and Engle 1993; Conway and Engle 1994; Passolunghi and Siegel 2001; Swanson 2008). These considerations also support Swanson's (2008) findings that children's development of WM involves two major components: selective attention and storage. Differences in mathematical problem-solving may not be related directly to the quantity of information that can be held in memory but rather to the efficiency of inhibition of irrelevant information, or selective attention. Considering this, we included measures of WM and selective attention independently, in order to understand their separate contributions to explain math performance.

Math performance and intelligence

In the psychometric tradition, general intelligence (the *g* factor) is defined as the use of deliberate mental operations to solve novel problems (i.e., tasks that cannot be performed automatically). These mental operations often include drawing inferences, concept formation, classification, generating and testing hypothesis, identifying relations, comprehending implications, problem-solving, extrapolating, and transforming information (Kane and Gray 2005; McGrew 2009; McGrew and Evans 2004). Recently, fluid intelligence (*gf*) has been assumed as synonymous or closely related to the general or *g* factor of intelligence (Ackerman et al. 2002; Blair 2006) and has been explained on the basis of executive functions related to perception, attention, and WM (Ackerman et al. 2005; Engle et al. 1999; Kane et al. 2005; Shimamura 2000; Smith and Jonides 1999). In fact, in the three-stratum theory of intelligence, Carroll (1993) distinguishes between narrow, broad, and general cognitive ability. This latter construct represents *g* factor or general intelligence, broad level embodies intermediate level abilities (e.g., fluid and crystallized intelligence, and processing speed), and narrow level expresses specific abilities such as the ones represented in the WM construct.

Research findings demonstrate close links between measures of WM and measures of learning and intelligence (Lee et al. 2004; Swanson and Siegel 2001). It is probable that the executive system of WM (which manages a number of goals, representations, and procedures for problem-solving, which require controlled attention) acts such as the critical WM factor for fluid intelligence tasks (Fry and Hale 2000; Oberauer et al. 2003).

Although there is evidence in the literature that intelligence is related to math performance, several studies point out that WM scores seem to be better predictors of math achievement than measures of intelligence (Andersson 2008; Bull and Scerif 2001; Lee et al. 2004; Swanson 2004; Swanson and Beebe-Frankenberger 2004). In mathematical abilities, CE and selective attention seem to be mostly involved as a source of attention control, enabling the focusing of attention and the division of attention between concurrent tasks and attention switching.

More recently, Lee et al. (2009b) argued that WM is one of the constituent measures of intelligence, and the predictive power of these two cognitive measures in math performance is highly dependent on the characteristic of the tasks. To address this issue, we will adopt a set of standardized tests that measures the different components of Baddeley and Hitch's (1974) model.

Taking into account that the three-stratum model (Carroll 1993) integrates different levels of cognitive abilities, we consider WM as a narrow ability, selective attention as a broad ability, and general intelligence as a general cognitive ability. Selective attention appears as a test for measuring processing speed, i.e., the ability to perform automatic cognitive tasks, particularly when measured under pressure to maintain focused attention (McGrew 2009). Considering this, the present study seeks to predict mathematical learning by certain cognitive factors (WM, selective attention, and general intelligence). Also, these mathematical skills included story problems as well as other math domains, namely measurement skills.

Method

Participants

A total of 103 third graders from two public primary schools (51.5 % males and 48.5 % females) from the southern region of Portugal participated in the study (88.3 % Caucasian, 11.7 % Black). Participants' age ranged from 8 to 9 years old (approximately 99 months, 55.3 % aged 8, while 44.7 % aged 9). The sample was randomly recruited and was not homogeneous in terms of race and cultural background, as is typical in Portuguese schools. Moreover, from preschool to primary public school, Portuguese was the only language of instruction in the classroom. All children speak Portuguese as their native language. Further details regarding parental occupation, education, and ethnicity were not reported. Previously, we carried out a preliminary study with a group of 30 third grade children (53.3 % males and 46.7 % females) for the translation and adaptation study of WMTB-C subtests. These preliminary study participants were not included in the subsequent main study. In both studies, none of the participants had any physical, sensory, or behavioral impairment and/or other nationalities. Previous parental consent was obtained for each participant.

Instruments

Working memory (WM)

Working Memory and Test Battery for Children (WMTB-C; Pickering and Gathercole 2001) provide a broad-ranging assessment of WM capacities, and it is to be used with children between the ages of 4 and 15. It consists of nine subtests designed to tap the three main components of WM: the CE, the phonological loop, and the visuospatial sketchpad. For the CE assessment, we used listening recall, in which the children had to verify the veracity of a series of sentences, while remembering the last word of each sentence. In counting recall, the children had to count the number of dots in a series of arrays, while remembering the successive tallies of each array. Finally, in backward digit recall, children had to maintain the forward sequence of digits while recalling them in reverse order. Four subtests are designed to measure the phonological loop function: digit recall, word list matching, word list recall, and nonword list recall. In these subtests, a series of items is presented orally and children then attempt to recall the list in the original sequence. Finally, to assess the visuospatial sketchpad, we used block recall, in which a series of blocks are tapped in a three-dimensional array, and children attempt to tap them in the same sequence. In mazes memory, children view a path traced by a finger through a two-dimensional maze and then attempt to recall it. A same scoring procedure was used in all subtests (one point for each correct answer and zero points for incorrect answers).

The search of short (one-syllable) words for the Portuguese version of the WMTB-C measure was identical to the English version. Some WMTB-C subtests were translated into Portuguese by experts in the field such as listening recall, word list recall, and word list matching and nonword list recall. Specific points were considered such as including simple and common words to be familiar for young children and guaranteeing that no one-syllable stimuli was repeated more than once across trials within a test. The nonsense words from nonword list recall were created using the same pool of sounds (phonemes) as the words used in the word list recall subtest.

This battery showed good internal consistency (Kuder-Richardson 20—KR20) for all the subtests of the phonological loop: (digit recall with KR20=0.82; word list recall and word list matching, each of them with KR20=0.86 and nonword list recall with KR20=0.78). For the visuospatial sketchpad subtests that include mazes memory and block recall, the coefficients were (KR20=0.75 and 0.78, respectively). Finally, the two CE subtests, listening recall and backward digit recall, revealed good internal consistency (KR20=0.80 and 0.85, respectively); only counting recall subtest had the lowest internal consistency with KR20=0.70.

Selective attention

The *d2* test (Brickenkamp and Zillmer 1998) is composed of 14 items with letters "d" and "p" with one, two, three, or four dashes arranged either individually or in pairs above and below the letters with a total of 658 items. Each child is given 20 s to scan each line and mark all "d's" with two dashes. The incorrect answers were scored with zero, and the correct items could achieve more interval values according to each child's performance. The internal consistency was a Cronbach's value of 0.90. Also, according to Bates and Lemay (2004), *d2* is a consistent and valid measure of visual scanning accuracy and speed.

The g factor

The *g* factor was assessed through Raven's Progressive Color Matrices (Raven et al. 1995), which is designed for children and consists 36 items, distributed in three sets of 12 items (A, Ab e B). The children were asked, without a time limit, to find the missing piece in a set of matrices that become progressively more difficult. The score for each correct answer is of one point and for incorrect answers, zero points. The test revealed good internal consistency (KR20=0.80).

In order to assess math performance, we created two mathematical domains that included some exercises to be solved without a time limit, so as to examine the following parameters: arithmetic story problems (addition and subtraction) and measurement skills (length and area). These tests were designed according to the math programme for the third year of primary education with the approval of the Educational Evaluation Department (GAVE) of the Portuguese Education Ministry.

Arithmetic story problems

This subtest has six arithmetic questions (three additions and three subtractions). Some examples of given problems are: "In a bus there are 17 people, 4 get on. How many are there at the moment? Or, John found 2 Euros and 60 cents on the floor. He puts the money in his wallet. Now he has 3 Euros and 90 cents in his wallet. How much money did he have in his wallet before he made the discovery?"

Measurement skills

This section analyses children's knowledge of length and area measurement. For the measurement of length, we assessed children's understanding of iteration of units and need for identical units of measure. We provided children with two 7-cm rulers, one marked at equal intervals, so that every unit was identical, and one marked at unequal intervals. Participants had to choose between the rulers to measure the length of a 7-cm stapler and a 9-cm book. We recorded children's choices, the way they measured each object, and their justification for their choices and methods. For area measurement, we explore children's conceptions of the unit–attribute relationship by eliciting their spontaneous ideas about how to find the “amount covered by” a square 6 cm on each side and a right isosceles triangle with a 6-cm side. We began to cover the cardboard square with three plastic rectangles, two plastic squares, and two plastic triangles. The interviewer asked the children if an answer of 7 was a good measure and they had to justify their answer. After that, the interviewer filled the same cardboard square with nine plastic circles and asked if nine was a good measure of the area.

We used two different scoring procedures: for arithmetic story problems, the scores were one point for correct exercises and zero for incorrect answers (Vergnaud 1983); for measurement skills, the scores were zero for inexistent answers, one point when the student tried to justify their choice (even when the answer was wrong), and two points when the answer was correct and well justified (Lehrer and Chazan 1998). The internal consistency for measurement skills and arithmetic story problems ranged from 0.72 to 0.75, respectively.

Procedures

Cognitive and mathematical measures were applied individually to all participants in the same sequence in two individual sessions which lasted about 40 min including a short pause. We applied the WM, *g* factor, and mathematical tasks without a time limit. Only the selective attention test was timed with a time-out of 20 s at each point. In each task, there was at least one practice trial before the testing phase to ensure that the children understood the task. All instructions regarding each task were presented orally. The order of test administration was held constant. We administered the WM tasks first, followed by the selective attention, the *g* factor and, lastly, the mathematical tasks. We analyzed the data with IBM SPSS 18.0 Statistical Package.

Results

As a first step, we performed a correlation analysis in order to examine the relations between cognitive and mathematical measures. The results from the descriptive statistics and the correlations between specific and composite scores for the cognitive measures and mathematical exercises are displayed in Table 1. Because in WMTB-C there are several measures of the different WM components, we combined the scores to deal with them in the regression analysis. All of the variables were approximately normally distributed, with skewness and kurtosis values less than 2.0. Only measurement skills (skew=3.88) revealed a higher value, however, below the cutoff of 7.0 suggested by West et al. (1995).

All measures correlated significantly with each other. The relationship between some WM components (i.e., CE, visuospatial sketchpad, and phonological loop), the selective attention, *g* factor, and math tasks were significant, with r ranging from 0.195 to 0.779. In Table 1, we find high correlation coefficients between the CE and arithmetic story problems

Table 1 Descriptive (mean and standard deviation) and correlation coefficients between cognitive and math measures

Measures	Mean	SD	1	2	3	4	5	6
1. *g* factor	28.35	6.80						
2. Attention	85.18	24.86	0.349**					
3. PL	81.47	25.08	0.445**	0.407**				
4. VSSP	28.22	13.68	0.705**	0.408**	0.493**			
5. CE	80.12	26.32	0.779**	0.329**	0.450**	0.698**		
6. Arithmetic story problems	2.98	1.57	0.653**	0.401**	0.403**	0.586**	0.717**	
7. Measurement skills	1.85	2.12	0.481**	0.279*	0.195*	0.478**	0.530**	0.219*

SD standard deviation, *PL* phonological loop, *VSSP* visuospatial sketchpad, *CE* central executive

* $p<.05$; ** $p<.01$ (two-tailed)

(r=0.717, $p<.001$). Lastly, the visuospatial sketchpad also showed a significant correlation with arithmetic story problems (r=0.586, $p<.001$).

In order to evaluate the relationship between the cognitive variables and mathematical performance, we also performed a set of multiple regression analyses (method enter) considering the different math curricular areas (arithmetic story problems and measurement skills) as criterion, and the CE, the visuospatial sketchpad, the phonological loop, the selective attention, and the *g* factor as predictors. We opted to introduce WM dimensions in the first step, adding selective attention in the second step, and general intelligence in the third step based on the three-stratum model (Carroll 1993). According to this model, WM reflects narrow abilities, selective attention may be considered as a broad ability, and general intelligence appears as a higher level ability. Previously, we tested regression assumptions with the use of collinearity statistics. All the VIF scores were below 5.0, which imply that these variables do not contain redundant information (Field 2005).

Results of the regressions are summarized in Table 2. By using arithmetic story problems as the dependent variable, we found that WM components (CE, phonological loop, and

Table 2 Summary of hierarchical regression analysis for cognitive measures predicting arithmetic story problems and measurement skills (N=103)

	Arithmetic story problems			Measurement skills		
Predictor	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
(Constant)						
PL	0.072	0.022	0.019	0.036	0.006	0.002
VSSP	0.195	0.113	0.081	0.191	0.143	0.106
CE	0.531**	0.517**	0.447**	0.511**	0.502**	0.442**
Selective attention		0.224**	0.207*		0.131	0.112
g factor			0.129			0.149
R^2	0.519	0.553	0.558	0.459	0.470	0.478
Adjusted R^2	0.504	0.535	0.536	0.442	0.449	0.451
ΔR^2 change in adjusted R^2	0.519**	0.034**	0.005	0.459**	0.012	0.007

SD standard deviation, *PL* phonological loop, *VSSP* visuospatial sketchpad, *CE* central executive

* $p<.05$; ** $p<.01$ (two-tailed)

visuospatial sketchpad) accounted for 51.9 % of the variance when entered alone into the regression model (step 1), although only the CE variable is significant (β=0.531, p<.01). Adding selective attention after the WM components (step 2) resulted in a significant increment in R^2, but of only 3 % of the variance. In step 3, all cognitive measures accounted for 55.8 % of the variance, although, the g factor did not increase R^2 significantly.

Considering measurement skills as the dependent variable, we found a similar pattern of results to those used to predict arithmetic story problems. As shown in Table 2, WM components alone predict 45.9 % of the measurement skill variance. Adding all the cognitive measures in the regression model (step 3) incrementally explains 47.8 % of the measurement skill variance. However, the increment in R^2 is not significant, and only the CE measure is positively and significantly related with arithmetic story problems (β=0.442, p<.01).

Overall, these results showed a significant contribution of WM in the two domains of math performance. Its contribution to the shared variance is significantly higher than both the g factor and selective attention. At same time, the importance of WM, and specifically the CE (more than the other components), explains the large amount of variance in the prediction of math results.

Discussion

This study explored the contribution of cognitive processes (WM components, selective attention, and general intelligence) to a range of mathematical skills in elementary school age children. The multiple regression analyses revealed the contribution of WM (especially the CE component) to children's mathematics performance (arithmetic story problems and measurement skills).

According to our findings, the mathematical domain involved in this study, such as arithmetic story problems and measurement skills (e.g., length and area), seem to require executive cognitive functions, as proposed in the literature (Bull et al. 1999; Bull and Scerif 2001; Geary 2004; Holmes and Adams 2006; Maybery and Do 2003; Swanson 2004). For example, Holmes and Adams (2006; also see Holmes et al. 2008) found that the CE predicted performance in several math domains (number and algebra, geometry knowledge, measurement skills, data handling, and arithmetic story problems).

Also, data from this research showed that the WM CE was the most important predictor of the variance on arithmetic story problems and the sole predictor on measurement skills. This seems to be consistent with the view that CE capacity is related to arithmetic story problems and different types of math problems (see for review, DeStefano and LeFevre 2004), showing the relevance of executive functions in elementary learning and novel problem-solving. Recent research from Meyer et al. (2010) demonstrated a higher impact on math performance of both CE and visuospatial sketchpad—contrarily to phonological loop.

Moreover, selective attention was closely related to achievement in arithmetic story problems. Several studies have assumed that selective attention can be observed in this mathematical domain (McLean and Hitch 1999; Passolunghi and Siegel 2001; Swanson and Beebe-Frankenberger 2004). For example, in an addition task of two- or three-digit numbers, some digits are selected for specific roles (e.g., first addend), while the others are held, but not used in the current operation.

In the literature, the CE and selective attention skills are thought to be involved in arithmetic story problem-solving. This occurs due to the significant requirements for text comprehension where incoming information must be integrated with previous information maintained in WM for problem-solving. Thus, the incoming problem information must be examined for its relevance and then selected or inhibited for its importance in order to solve that specific problem. Additionally, a number of authors claim that differences in WM span may not be related to the quantity of information that can be held in memory but rather to the efficiency of inhibition of irrelevant or no-longer-relevant information (Passolunghi et al. 1999; Passolunghi and Siegel 2001).

Selective attention plays an important role in WM (see Miyake and Shah 1999 for details). However, in our study selective attention tasks result in lower variance when explaining math performance. Our results also show that the measure of attention was not particularly strongly correlated with the measure of WM. In this sense, the selective attention tasks used in this study was operationalized differently from Cowan and Engle's conceptualization of WM (Miyake and Shah 1999). According to Cowan's model (1999), attention was seen as "an enhancement of the processing of information in the exclusion of other concurrent information" available (p. 63). Thus, attention is one among other mechanisms (such as memory activation and executive mechanisms as well as long-term retrieval mechanisms) that contributes in processing WM tasks. Engle et al. (1999) also made important contributions to the area and conceptualized WM as consisting of an activated portion of long-term memory plus controlled attention. Controlled attention is used to achieve activation of long-term traces to maintain activation as well as to inhibit activation. Both conceptualizations of attention are far from the one used in the tasks in this study. Thus, we would suggest that further studies should include attentional tasks closer to the conceptualizations previously mentioned. Conceptually, *d2* seems to be substantially different from the more familiar tests of speed of processing used in the studies mentioned in the literature. Despite these limitations, *d2* is one of the most respectful tests for measuring selective attention. This reinforces that selective attention and WM are correlated but separate constructs. Thus, selective attention plays a different role when explaining different types of math tasks. This stands out as a major contribution of our research.

Finally, let us point out that the *g* factor doesn't appear to be significant in the regression analysis—the explained variance on math tasks is assumed by both WM and selective attention measures. However, if we consider Table 1, the results suggest that *g* factor is correlated to both arithmetic story problems and measurement skills. Considering this apparent contradiction, WM seems to integrate intelligence (Ackerman et al. 2005) and selective attention (Engle et al. 1999), namely on measurement skills tasks. On arithmetic story problems, selective attention has a significant effect, but below the WM effect. Thus, by activating and inhibiting the cognitive processes, selective attention seems to play a significant role in solving arithmetic story problems (Conway and Engle 1994; Passolunghi and Siegel 2001; Swanson 2008).

Regarding reliability and generalizability of these results, we should take into account that this study was correlational and involved a small nonrepresentative sample size of third grade basic students. In order to overcome this limitation and to establish causal paths for these variables, experimental studies that include other attentional variables should be considered. Moreover, longitudinal studies should be carried out in order to examine the relation between selective attention and WM across ages. Future research should also focus more specifically on different components of the CE function (inhibition, shifting, and updating) and their potential role in the development of children's story problems involving arithmetic operations and measurement skills.

To conclude, this paper adds to the understanding of the implications of cognitive processes, especially of WM in children's maths achievement. This study also contributes to a better understanding of the relation between different cognitive processes and the several domains of math learning in primary education. Furthermore, the current study provides additional evidence for the stronger role of the CE in different mathematic competencies.

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Current themes of research:

Psychology of Education. Emotion and Decision-Making.

Most relevant publications in the field of Psychology of Education:

Campos, I. S., Almeida, L. S., Ferreira, A. I., & Martinez, L. F. (2012). Working memory as separable subsystems: A study with Portuguese primary school children. *The Spanish Journal of Psychology, 15*(2), forthcoming.

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Current themes of research:

Emotion and Decision-Making. Economic Psychology. Organizational Behavior. Human Resource Management.

Most relevant publications in the field of Psychology of Education:

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Current themes of research:

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